Citizen science on speed? Realising the triple objective of scientific rigour, policy influence and deep citizen engagement in a large-scale citizen science project on ambient air quality in Antwerp

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Abstract Citizen science projects are increasingly recognised as catalyst for triggering behaviour change and building social capital around environmental issues. However, overview studies observe recurrent challenges in many citizen science projects in terms of combining high levels of data quality with deep citizen engagement and policy influence. This paper reports on the findings of the CurieuzeNeuzen project (www.CurieuzeNeuzen.eu), a large-scale citizen science project on air quality in Antwerp, delivering results in the three areas described above. Through CurieuzeNeuzen, 2,000 citizens studied the air quality levels in and around Antwerp in 2016 and were intensively deliberating on possible causes and solutions. Surveys were conducted at the start and towards the end of the project, with participants stating that their participation resulted in changed views and behaviour towards air pollution, mobility solutions, and city planning. The findings were picked-up academically and contributed to policy debates on air quality at city and regional level.

Keywords: Citizen science; air quality; environmental democracy; behavioural change; Antwerp

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1 Introduction

Daily traffic volumes deteriorate air quality in and around cities, and call for an urgent transition towards a more sustainable mobility. Many scholars argue that technological innovations alone will not suffice to reach sustainability goals (e.g. Anable et al. 2012; Banister 2008; Chapman 2007). An actual change in the behavioural response of citizens is necessary, whereby insights in how individuals are influenced by collective customs are imperative (Schwanen, Banister, and Anable 2012; Hull 2008; Urry 2004).

A possible way for evoking behavioural changes is to invest in social capital, i.e. "the features of social organization such as networks, norms and social trust that facilitate co-ordination and co-operation for mutual benefits" (Putnam 1995, 67). In the environmental realm, this connection is also found: social capital is seen as a primary facilitator of civic action, e.g. behavioural change to reduce one's impact on the environment (Wakefield et al. 2001; Conrad and Hilchey 2011). Building social capital for sustainable development requires not only collective action by groups of citizens, but also participatory policy-making as argued by several scholars (Gerometta, Haussermann, and Longo 2005; Seyfang and Haxeltine 2012; Moulaert et al. 2005; Wakefield et al. 2001; Agyeman and Angus 2003).

Since the 1990s, one observes a "mushrooming of high quality and innovative community development initiatives in European cities" (Moulaert et al. 2005, 1970), many initiated as a response to the prevailing technocratic approaches amongst others in the field of mobility and spatial planning. Several grass roots initiatives working towards more sustainable cities have looked at citizen science to support their goals and agendas. Aside from influencing local policies, citizen science projects could be a stepping stone to build the required knowledge base, trigger behavioural change and strengthen at the same time the social capital through the actual involvement of the stakeholders and the broader public (Newman et al. 2011; Muro and Jeffrey 2008). In this way, citizen science projects can potentially catalyse transitions towards sustainability at the local level (Whitelaw et al. 2003; Theunis, Peters, and Elen 2017).

Most of the citizen science projects have at least the double objective of scientific rigour and citizen engagement and awareness raising. However, having an influence on policy decisions related to the field of inquiry, and/or making sure that the results are used in policy debates, is often put forward as a third objective. This ensures that people are not monitoring for the sake of monitoring, but they feel that the resulting data is relevant and used by policy-makers (Conrad and Hilchey 2011). In our opinion mastering the triple objective is beneficial to increase the chances on bringing about behavioural change of citizens and at the same time getting accepted both by "academia" and politics.

Here, we present the results from the *CurieuzeNeuzen* project (www.*CurieuzeNeuzen*.eu), a large scale citizen science project that has monitored air quality in the city of Antwerp (Belgium). In particular, the project focused on traffic-related emissions, as traffic congestion is amongst the main contributors to local air quality variability in Antwerp. This paper's focus lies on the (social) dynamics that resulted from the *CurieuzeNeuzen* project.

One author has been actively involved in the research project team and the Ringland Academy and provides detailed inside information on the whole process. The other author is external to

Ringland, however closely following the mobility debate in Antwerp. In our opinion, this mix of both perspectives is of value here.

This paper contributes to the expanding field of citizen science by specifically addressing questions about scientific credibility, policy adoption of the results and the engagement of and effects on citizens in the project, as mastering those three challenges simultaneously seems the most difficult for citizen science projects in general. More specifically: how does the *CurieuzeNeuzen* project master these traditional citizen science challenges? Why did almost 2000 citizens engage in the measurement of urban air quality? Are the results eventually acknowledged and used by policy-makers? Does the scientific experience appear to make people more aware of air quality risks in their living environment? Does participation induce a change in opinion about different mobility-related policy measures and does it influence (self-reported) behaviour? In this respect, the project is framed and discussed within the literature on environmental monitoring citizen science projects. The answers to our research questions are derived from two online surveys accompanying the citizen science project. Other data sources included participant observations, informal research log books, observations and meeting minutes of the project team, media reports, and audio-visual material.

In Section 2, the Citizen Science literature and challenges are elaborated. The third section describes the *CurieuzeNeuzen* project in detail. Sections 4 and 5, respectively, show and discuss the results of the project and the dynamics it provoked, after which conclusions are presented in a sixth section.

2 Citizen science projects

Although citizen science has already a long tradition (Silvertown 2009; Conrad and Hilchey 2011), especially with respect to the contribution of amateur scientists in the fields of birding (Sullivan et al. 2009), history, and astronomy (Raddick et al. 2010), the concept "Citizen science" has only been included in the Oxford dictionary in 2014. It is nowadays described as "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientist" (Oxford English Dictionary, 2016). Recently, citizen science has increasingly gained legitimacy as a scientific discipline with respect to both decision making and "mainstream science" (Storksdieck et al. 2016; Freitag, Meyer, and Whiteman 2016). As the benefits of citizen participation in science projects and the accumulation of experience in citizen science outweigh the limitations, citizen science programmes are starting to push the limits of the citizen science tradition further and further (Tregidgo, West, and Ashmore 2013; Conrad and Daoust 2008). Particularly in ecology and environmental sciences involving citizens is booming (Conrad and Hilchey 2011; Dickinson, Zuckerberg, and Bonter 2010). Large-scale environmental science even necessitates citizen science (Silvertown 2009, 467) since obtaining data at a fine spatial resolution is often deemed too costly, especially in times of economic crisis and associated budget cuts (Whitelaw et al. 2003; Conrad and Hilchey 2011).

A widely accepted categorisation of citizen science projects is based on the extent to which participants are involved in the project's origins and the project process, ranging from setup and design to implementation and evaluation. Going from little to almost complete involvement of participants, Bonney, Ballard, et al. (2009, 17-8) distinguish between contributory,

collaborative and co-creative citizen science projects. Most of the citizen science projects adopt a *contributory approach*, in which participants are only involved to help collect data. However, it is argued that the more involved the participants are, the more impact citizen science projects can have on them in terms of an improved understanding of environmental issues and of science in general (Evans et al. 2005). *Collaborative projects* are also designed by scientists, but aside from the participation of citizens in the collection of data, they also have a say in the roll-out of the research project. Finally, *co-created projects* originate from at least a part of the citizens themselves, and are designed in combination with scientists. Contrary to the former two approaches, citizen participants are thus involved in the whole scientific process (from design to evaluation) (Bonney, Ballard, et al. 2009). Nevertheless, the evidence about the extent to which the generated scientific literacy, social capital and environmental democracy building leads to environmental benefits is anecdotal until now (Conrad and Hilchey 2011; Dickinson et al. 2012).

The challenges that citizen science projects generally face are related to the three objectives they often combine: (1) collecting large scale scientific data, (2) raising awareness amongst the broader public and looking for real citizen engagement in the matter, and (3) serving society and encouraging political impact. (1) and (3) can be regarded as the external objectives of the citizen science project, they relate to the scientific results and the effects on policy. While the second objective can be seen as an internal objective, referring to evaluating these projects in terms of improving scientific literacy, building social capital, and trigger behavioural change. However, realising all three objectives at once seems difficult in many citizen science projects and requires significant effort (Bonney, Cooper, et al. 2009; Brossard, Lewenstein, and Bonney 2005).
Often scientific credibility of the monitored data is questioned by scientist and/or politicians. They express doubts with regard to data fragmentation, inaccuracy, objectivity, experimental design, monitoring expertise of volunteers, quality assurance, etc. (Conrad and Hilchey 2011) In particular, for monitoring air quality the validity and quality of the used materials/devices and methods become more important than for example in birding or ecosystem programmes.
Furthermore, most citizen science results are only scarcely adopted by decision-makers (Conrad and Hilchey 2011). As a possible solution several authors refer to the necessity of "strategic" or "innovative" partnerships in which citizens, academic institutions and government bodies cooperate in citizen science projects. Hence, it is important that the act of monitoring is not the final aim, but that there is a proactive orientation towards influencing policy agendas and measures. As useful and detailed (large scale) citizen-generated data is much sought after by government bodies, fruitful strategic partnerships with government bodies and knowledge institutes can be build (Dickinson et al. 2012; Conrad and Daoust 2008).
To maximise the impact it is equally important to get the results published, not only in academic literature, but also for a broader audience of citizens and decision makers (Conrad and Hilchey 2011).

Recently, the internal values of such projects have become a growing theme within the citizen science literature. Hence, aside from tackling the challenges of scientific rigour and policy adoption, this paper also specifically pays attention to the interest and motivational aspects of volunteers, to scientific literacy (knowledge on the topic) and awareness raising aspects (sharing of information, attitudes towards policy measures).

3 "Curieuzeneuzen" project

3.1 The project's (grass)roots

The Citizen Science project *CurieuzeNeuzen* (a wordplay in Antwerp dialect that relates to "nosing around") was launched by the Ringland Academy, a think tank within the Ringland citizen movement (http://ringland.be/). Ringland started in 2014 as a bottom-up initiative within the city of Antwerp (population 517,000[i]), and was established by a collective of spatial planners, architects, and other professionals. The Ringland initiative envisions a new future for the city of Antwerp by proposing a complete redesign of the Antwerp mobility system and a "capping" of the Ring road that traverses the city. In the Ringland plan, this circular highway would be moved entirely underground in a tunnel system. This would entail a substantial improvement of air quality and allow large-scale development of new green areas within the inner city (Van Brusselen et al. 2016). With the aid of an attractive and innovative (multi)media campaign, Ringland has developed into one of the most prominent civic initiatives within Europe these days, mobilising thousands of citizens to support their campaign. The mobility debate in Antwerp is already going on for a long time, with subsequent infrastructural master plans of the Flemish government being rejected through the lobby and advocacy work of increasingly strong citizen movements (Van Brussel, Boelens, and Lauwers 2016). Ringland is different, however, from many other citizen movements by incorporating three different roles in the mobility debate in the city of Antwerp in recent years. The role of citizen movement (or "activist group") is combined with the role of knowledge network (feeding the public debate at regular intervals with ideas around mobility, city planning, and quality of life), and finally that of policy influencer through their participation in policy preparation processes and high level negotiations. For example, in 2015, through the active advocacy work of Ringland an "intendant" was installed by the Flemish government with the mandate to demine the heated mobility discussion and to harmonize the vision of the different stakeholders. In April 2017, a breakthrough accord was negotiated with all mayor players and political parties promising a gradual capping of the ring, with more ambitious targets for sustainable mobility by 2030, and a more inclusive governance system for all large-scale infrastructure works in the province of Antwerp. The intendant managed to break the deadlock, especially by giving the different parties a more equal position in the policy debate. Because of this, the intendant has gained credibility and respect amongst the stakeholders, and through positive reporting in the media, possibly also amongst the wider public.

The Ringland Academy has brought together a wider group of experts and professionals beyond the core Ringland team. They offer ad-hoc inputs into Ringland's activities, contribute to ongoing study work, and develop projects related to one of the core-themes of Ringland. The *CurieuzeNeuzen* project has been one of the main outputs of the Ringland Academy up to now. Aside from its objective to better understand air quality problems in Antwerp, *CurieuzeNeuzen* was created to sensitise and trigger Antwerp citizens (and politicians) about their living environment and the urgency for action with respect to traffic-related air pollution.

The idea of the project was originated in the Ringland Academy, but the project was fully designed and implemented by a temporary project team of volunteers. They were identified during the annual Ringland music festival by putting up posters with vacancies for specialists in various disciplines, for which not only sympathisers but also other inhabitants and passers-by in general could apply. During the festival, most of the applications were completed and a

diverse project team was established with volunteer-programmers, -database analysts, -communication experts, -scientists, and others. For a majority of the team members it was their first experience with volunteer work for Ringland.

3.2 Setup of the curieuzeneuzen project

The *CurieuzeNeuzen* project was finally turned into an air quality measuring project, focusing on the average nitrogen dioxide (NO_2) concentration at a household resolution per street. NO_2, was measured using a cost-effective standard protocol during the month of May 2016. The NO_2 pollutant was chosen as indicator for air quality here, since the project is to be situated in a mobility context and abundant scientific evidence shows that air pollution by NO_2 is more traffic-related, than, for example, particulate matter (Carslaw 2005).

From meeting minutes of the project design phase it can be derived that the *CurieuzeNeuzen* team was not willing to compromise on scientific relevance for the sake of citizen participation. Therefore, after a review process of different NO_2 measurement devices, the project settled for Palmes diffusion tubes to map NO_2 concentrations[ii]. The team preferred the tested Palmes tubes (Palmes et al. 1976), rather than digital devices for cost-effectiveness and simplicity reasons, allowing to reach out to large numbers of citizens. Several studies show that the passive monitoring method is complementary to the continuous measurements based on chemiluminescence used in reference methods (Lewné et al. 2004). The performance values of these tubes have complied with the European Union data quality objectives for indicative measurements of ambient NO_2 concentrations.

Additional quality control steps were undertaken to strengthen scientific rigour. At different phases of the project, the team consulted leading experts on air quality to review ideas and options. In addition, permission was sought from the Flemish Environmental Agency (VMM) to allow for the calibration of the Palmes tubes in the eight reference monitoring stations located in the study area. In an effort to further improve data reliability, the team designed a standardised and foolproof set-up, which had the additional advantage of creating visibility for the research project.
A measuring setup (as illustrated at www.curieuzeneuzen.eu/en/about/) was used, whereby a measuring board was attached to a window pane, containing two Palmes diffusion tubes sampling NO_2 selectively from the ambient air. The board allowed the tubes to be hung on a fixed distance from the building, improving the measurement's standardisation. The total amount of NO_2 collected in the tube's gel is a measure of the mean concentration of NO_2 in ambient air. For quality control purposes two tubes were used at each location and the mean value of those two measurements was used for data analysis. Simple instructions were designed with a lot of visuals and supported by video. Finally, a tight plan was designed to guarantee the swift distribution and collection of 2,000 sets, and the exact recording of measurement times, height, etc. After four weeks, the tubes were collected, stored in a fridge and brought to the lab for analysis.

The project was announced on March 22 in local newspapers, on social media, and on the Ringland website. The initial goal was to distribute 1,000 sampling packages amongst citizens around Antwerp in order to obtain a fine-meshed monitoring network of air quality data, suitably covering the study area. But within 12 hours after the launch of the project website, the number of volunteers already exceeded the initial 1,000 participants limit. This illustrated that

there was a large interest – and that the possibility of "measuring air quality on the doorstep" was somehow dear to the inhabitants of Antwerp. In total, about 2,600 people ended-up registering for participation. To accommodate for the unexpected success, it was decided to raise the participant number to 2,000 monitoring points. The selection of who finally could participate was based on several criteria, especially focused on having measuring points that were suitably equidistantly distributed across the inner city of Antwerp and its neighbouring districts; and obtaining a mix of individual citizens, schools, and other institutions. Eventually 1,996 sampling packages were installed, of which 1,840 by citizens, 51 by schools, 10 by hospitals, 45 by companies, and 15 by other organisations. Additionally, 35 points were located in public parks and viaducts crossing the ring road highway. Participation in the project was free and on a 100% voluntarily basis.

Participants could collect their sampling packages on four different pick-up moments at one central location (theatre "De Roma") between April 24-30 (2016). A sampling package included a sampler board, the samplers themselves, as well as a clear description on the scientific protocol to follow. The actual air quality measurement started on April 30 and ended on May 29. At the end of the campaign, sampling packages were handed in again at the same central location. During the measurement campaign, participants were asked to fill in technical questionnaires sent by email to verify the location and height of the tubes, and to document exceptional issues which could affect the measurements (e.g. a fire nearby, tubes getting damaged, etc.). With 98% of the measurement sets returned[iii] for scientific analysis, the project realised an exceptional return rate. The volunteers engaging in the *CurieuzeNeuzen* project team were also involved in the data-interpretation. To make this possible, the data was visualised on maps and, in several sessions facilitated by two experts, the team critically reviewed the findings neighbourhood by neighbourhood, checking for consistency and anomalies, drawing conclusions, and identifying possible patterns.

All participants were invited to the Ringland Festival on 25 June, as the preliminary results were presented there on a large 4x4m canvas, with an estimated 1500 people coming to view and discuss the results. A log book was provided for participants to note down the results which stood out, together with possible clarifications. The preliminary findings were also picked-up widely in the local and national audio-visual media and papers, and on social media. Along with the preparation and validation of the air quality results, an online survey was launched in order to know what participants learned from their participation in the citizen science project and how this changed their attitude towards mobility measures, behaviour, etc. Also, the reasons for participation were probed and demographical data was gathered. The final results were presented on a feedback event at a large theatre (De Roma, in Antwerp on 22 October 2016) for a public of around 900 participants. During the event, leading policy-makers, including the head of the European Environmental Agency, a representative of the mayor of the city, and the head of Ringland were asked to comment on the findings and their implications for the city of Antwerp. After the more general presentation, people were asked to pass by the information stands of the *CurieuzeNeuzen* results of their own neighbourhood. They engaged in the verification of the results (coloured dots on the map) and were asked to think of possible explanations, especially were results seemed rather deviant.

4 Results

4.1 Scientifically rigorous air quality data

Only a brief summary of the actual air quality measurement findings is provided here, mainly to demonstrate their academic and societal relevance. An in-depth discussion of these data is the subject of separate submission to another peer-reviewed journal.

A high-quality data-set was obtained, which revealed large differences in air quality across the city of Antwerp. NO_2 concentrations varied over short distances (100 m-scale) ranging from around 30 µg/m³ within urban greens to over 60 µg/m³ in traffic-congested street canyons (Figure 1). Multivariate data analysis identified that three factors (traffic intensity, street geometry, and the distance to the ring road) explained spatial variation in observed NO_2 concentrations.

Figure 1.

The *CurieuzeNeuzen* results contribute to the growing body of knowledge about urban air quality in two main ways. First, the between-street differences turn out to be larger than predicted by the existing computer models, that particularly appear to systematically under-estimate the level of pollution in the street-canyons. Secondly a substantially larger part of the sampling locations (45±10%) has concentrations that exceed the WHO yearly NO_2-limit of 40µg/m³, compared to what computer models predict (2%).

Aside from the quality control steps described in Section 3.2, networking with academics and experts was actively pursued throughout the project cycle to increase the chance of academic recognition and uptake. The fact that some members of the *CurieuzeNeuzen* team had a research background, although not in the area of air quality measurement, still helped to access and establish these academic contacts. Additionally, three universities were approached for technical and financial support. Once the plans became more specific, the Flemish Environmental Agency (VMM) and the VITO research institute, which does the modelling of air quality data in Flanders, were approached not only for technical advice but also to discuss how the research could contribute to ongoing research efforts. The fact that VMM had identified citizen science as one of its emerging research areas, facilitated collaboration, although the institute was careful not to rush in its engagements. By the time the data collection started, significant interest in the data-set was shown by these research institutes and at the time of writing of this paper, the different parties were comparing the empirical data with existing air quality models.

4.2 Fruitful cooperation with and adoption of curieuzeneuzen results by policy-makers

CurieuzeNeuzen engaged in different ways with the city administration. The project became national news during various stages of the campaign, gradually putting the air quality problems in Antwerp higher up on the political agenda. However, the ground work for the policy influencing agenda of *CurieuzeNeuzen* started earlier through initial contacts with the city administration.

Rather than publicly exposing the city administration or policy-makers and in line with the overall constructive approach of Ringland, meeting minutes and project team observations indicate that a dialogue was sought with the relevant administrative services, e.g. the environmental task-force of the city administration, responsible for the production of updated air quality maps. *CurieuzeNeuzen* submitted a modest funding proposal to a fund of the city

which supports small sustainability initiatives, covering only a fraction of the total budget. But more importantly, it became the start of a fruitful dialogue with the city administration, which initially was not at all convinced that the project would generate any relevant data. Through regular contacts trust was built, e.g. by sharing tentative results first with the city administration before making them public to allow them to prepare a balanced response. Later on, personal communication of the project team demonstrates that contacts with the political level were pursued. At the end of the campaign, there was broad-based support within the city administration for the overall campaign, both in terms of the air quality findings and the behavioural change it had triggered with the participants. The administration actively participated in the final symposium, by including two information stands during the event, a shared press conference, and a political representative participating in a panel debate.

Since *CurieuzeNeuzen* originated from Ringland, the main movement opposing the largest infrastructural plans of Belgium, getting buy-in from the political level was rather sensitive, yet happened in different ways. As soon as the campaign was launched it attracted media attention because of its scale and the overwhelming response to the first calls for participants. Local television stations and newspapers started picking it up on the day of the launch, national media followed soon after. Some leading politicians of opposition parties residing in Antwerp even decided to participate as citizens in *CurieuzeNeuzen*. As such, ignoring the campaign became difficult at the political level.

Meeting minutes, frequency of meetings and personal communication between members of the project team illustrate that in the period leading up to the announcement of the final results in October 2016, the political contacts intensified, culminating in a joint press conference to launch the findings with two city councillors, three universities, and Ringland. In the weeks after, opposition parties used the findings to question the air quality policies of the city of Antwerp and the Flanders regional government through interventions in the town council and in the Flemish parliament. Between October 2016 and January 2017, almost every week media were reporting about air quality news items, hereby regularly referring to the *CurieuzeNeuzen* project. As an example, the largest newspaper in Belgium featured an interview with the director of the European Environmental Agency in which he was asked to share his views about *CurieuzeNeuzen*:

> *"Antwerp has set the standards for Europe. Both regarding data quantity and quality the research projects is amongst the absolute top. From now on, I will use this research project as a school example when giving lectures, since the rise of both knowledge and citizen involvement is of major importance" (H. Bruyninckx, director of the EEA, as in PJBA, 24 October 2016)*

The political opinion on the CurieuzeNeuzen results was the subject of discussion in the written press and media. The political majority in Antwerp sought confirmation in the *CurieuzeNeuzen* air quality results for the "promising" policy measures they had already planned: the low emission zone (LEZ) in Antwerp and further investments in public transport. However, the opposition saw in the results an urgent call for more extensive measures and they insisted on more short-term actions, e.g. lowering the speed limits on the ring road, more frequent public transport services, and a park and ride strategy. By some it was proposed to include the ring

road itself to the LEZ (cf. now the within area of the ring, but excluding the ring), as the results showed that the ring road had a major negative influence on local air quality.

The results of the monitoring campaign raised an overall awareness for the theme of air quality and quality of life in the city. The findings of the project featured in several local newsletters of neighbourhoods. As such, activist groups used the findings to call local government to action. Furthermore, the results were also used by teams of architects working on the capping of the ring, and at an individual level, many stories were shared by citizens on how they looked differently at their environment due to the project. For all those who were not particularly aware of the problem before, the pamphlets and posters revealing the results and the local and national media coverage on the *CurieuzeNeuzen* project have raised a sense of urgency, and have made it a very visible and personal matter. That is also why in the areas with the worst air quality, some participants appeared not keen on publishing the results poster at home, due to the fear of a decreasing value of their house. Some schools were reluctant as well, for they feared to lose pupils due to the reported air pollution levels.

Furthermore, not all media coverage was contributory to the general knowledge accumulation and sensitisation on air quality issues and the necessary mobility behavioural change. Without any communication with the research team and regardless of the research scope and focus, the Antwerp Airport authority distributed promotion pamphlets stating that the *CurieuzeNeuzen* results proved that air traffic appeared not to have a major influence on the local air quality[iv].

4.3 Citizen Engagement and the Effects of Participation on Participants

4.3.1 Participant's Profile, Motivational Factors and Perceived Air Quality

As awareness about liveability and air quality issues affects all citizens regardless of their age, gender, family situation, and level of education, the project was aiming at attracting citizens with different backgrounds by communicating in easily understandable language and through popular media. Although the group of higher educated citizens with ecological interests was well represented, the project managed to reach out to a wider group of concerned citizens from different age groups, and social and educational backgrounds (see Annex I). Meeting minutes of the project team proves that additional efforts were taken to reach out to Antwerp citizens with a migration background as experience learns that they are using different media channels and are less likely to be reached by traditional citizen science initiatives. A sub-team raised awareness amongst representatives of the Muslim communities in Antwerp, resulting in the participation of around 30 families with a Muslim background. This is still limited but does show that additional efforts can improve the participation of hard-to-reach groups.

Participants received questionnaires before and after the publication of the *CurieuzeNeuzen* results. With response rates of around 76% for the first survey and 40% for the second survey, the survey findings provide a representative picture of the participants' perceptions.
When asked about motivational factors for participation, most of the participants reported to participate out of curiosity about the local air quality in their street (91.8 %). Other (or additional) reasons for participating were: raising the importance of air quality amongst neighbours and local passers-by (62.3 %), making the citizen movement Ringland known to a wider audience (59.9 %), and being intrigued by taking part in a real research project (39.8 %)(n=1,412). At the start of the measurement campaign, only 5% expected a good to very good air quality in

their street, compared to those who assumed it to be moderate (40%), or (very) bad (50%) (n=1,414). As the urban air quality was perceived quite negative, this emerged as a main driver to actually subscribe for participation. After having seen the published air quality results, 59% of the participants agreed that the air quality measurement conformed with their expectation (n=631). For some, the measured air quality results were better than expected (27 %), while 11% underestimated the level of ambient air pollution in their vicinity, leaving them with a worse scenario than initially presumed.

4.3.2 Outreach of the Project

Public outreach and awareness raising are critical components of citizen science projects. The impact of outreach can be assessed through different "circles of influence": (1) the participants themselves, (2) direct interactions between participants and others, and (3) information to the general public through press coverage and the visibility of the campaign in the streets. Accordingly, the surveys integrated questions that indicated the outreach. As the focus of the research was more on the impact of *CurieuzeNeuzen* on the participants than on the general public, surveys were targeting the participants. However, a rough indication of the project's influence on the public debate about air quality can be found through an analysis of the press coverage.

The *CurieuzeNeuzen* project is estimated to have reached 5,610 people directly (participants were asked about the number of people residing in their house, n:1,395). Indirectly, another (estimated) 35,400 persons[v] were approached by the *CurieuzeNeuzen* participants to discuss about the project (n: 660), especially friends, family members, and neighbours, and to a lesser extent colleagues and fellow social activity members (see Annex II). A tertiary outreach was achieved by the adoption of the *CurieuzeNeuzen* air quality results in the media (the written press, digital media, and the social media), where the project received nationwide interest. When the measurements started, *CurieuzeNeuzen* was an item on the Flemish television news at primetime (ca. 1,160,000 viewers), the same happened when the tentative results and later on when the final results were announced. Since the project announcement in March 2016, more than 70 newspaper articles were reporting on or mentioning *CurieuzeNeuzen* at local, regional, and national level, including one front page of a national newspaper, and at least three page 2 commentaries from newspaper editors. In at least four national radio programmes, well-known actors and artists mentioned their participation to *CurieuzeNeuzen*. In addition, with nearly 2,000 announcement boards (3D real-estate form) attached to houses in almost half of the streets in the inner city, the project was quite visible during the measurement campaign. Further promotion was done by (1) asking the participants to distribute short leaflets about *CurieuzeNeuzen* (50,000 copies) amongst their neighbours, (2) the large 4x4m canvas on the Ringland festival, and (3) by distributing posters with the actual measurement results to the participants so that passers-by could also see the results on a given street. Later on, team members were asked to do presentations about the project in schools, other civil society movements, and at two universities.
In September 2017, it was announced that the *CurieuzeNeuzen* team would receive the Science Communications Prize 2017 from the Royal Flemish Academy of Arts and Sciences for its contribution to science communication in Flanders.

The combination of communication strategies at different levels therefore resulted in large groups of citizens participating or hearing about *CurieuzeNeuzen*, both directly and through the

media. This was further re-enforced by the strong media profile of Ringland itself. The academic recognition of the communication efforts provides an additional indication of their relevance and uptake.

4.3.3 Effects of Participation on Attitude and Behaviour

Due to participation in the *CurieuzeNeuzen* project, participants reported to act differently or plan to do so in the near future (Figure 3). Amongst the biggest self-reported behavioural changes noted were: "informing other people about air quality", "selecting healthier biking and walking routes" and "greening my façade and street". The sensitizing objective has thus had its effect. Many participants already had quite a sustainable mobility pattern, with around 65% (n=655) indicating they were already using the bike a lot and limiting car use, but this number further increased to almost the full group after the project. Interestingly, a substantial group wanted to take advocacy action (from 8% before having seen the results, to 57% after the publication of the results). Finally, a large group caught the research virus, with 61% indicating they plan to do more research on air quality.

Participants were asked about their attitude change towards certain local upcoming or already established mobility measures in Antwerp compared to their initial attitude before the start of the *CurieuzeNeuzen* project (see Figure 2). The public support increased for almost all mobility measures compared to before the start of the project. A substantial number of people indicated they had a (much) more positive attitude towards an environmental-friendly city distribution system (57%), park-and-ride zones outside the city (51%), and public transport (51%). Interestingly, the participants were also more positive about measures which tend to be less popular, such as congestion taxes for cars (46%) and the introduction of a LEZ (34%).

A specific measure related to the Antwerp context is 'realising Ringland' (cf. Section 3.1) which brought about the most change in attitude, approximately 60% indicated being (much) more positive towards it. This score can not only be explained by the profile of the participants, which counted a good number of people which already supported Ringland. From the first survey, we concluded that there was at least a group of 30%-40% whom were not necessarily supporting Ringland at the start of the project. Another explanation might be that the Ringland concept precisely addresses the air quality aspect by capping the ring road and by choosing for a radical modal shift. Contrary to this, the alternative option provided by the government: "the Oosterweel Link" is associated with more traffic-related air pollution and therefore the least moving of all, causing only about 13% of positive change in attitude and 35% becoming (much) more negative.

Figure 2.

Figure 3.

5 Discussion

Citizen Science projects can offer a wealth of information, and can reach large scales and fine resolutions for data collection and monitoring. But the practice is not yet universally accepted

as a valid scientific method. However, due to the expanding field and experience, citizen science is gaining scientific legitimacy by its attempts to account for credibility and validity issues through refining citizen-scientists protocols, the increasingly closer collaboration between scientists and citizens, etc. (Bonney et al. 2014). This paper on the *CurieuzeNeuzen* project results and dynamics contributes to the expanding citizen science field and elaborates on the triple objective of scientific rigour, policy influence, and deep citizen engagement, necessary for accumulating social capital in the transition towards a more sustainable development, and mobility in particular. While previous sections discussed the citizen science project design, process, and outcomes, this section further unpacks the underlying dynamics, success factors, and limitations.

5.1 Right Moment and Place for Citizen Science?

External factors created a sense of urgency around air quality issues in Antwerp. The mobility situation around Antwerp has deteriorated over the years; it is now one of the main traffic hotspots in Europe. Ringland, other local civil society groups, such as Ademloos, and academics have raised awareness about the associated air quality and environmental health risks, pushing the topic gradually higher-up the political agenda. Earlier plans to improve the mobility situation were repeatedly rejected because they did not address the health problems, nor the lack of green areas, and quality of life. Meanwhile, many citizens became eager to learn whether the air quality was indeed so problematic in their street. *CurieuzeNeuzen* used this window of opportunity by offering access to a free but reliable measurement devices. In addition, several research institutes and governmental bodies were looking for large-scale empirical air quality data-sets to validate the existing computer models, and possibly as baseline to assess the impact of new mobility measures.

At least four internal factors played a prominent role in amplifying the effects of the project. Firstly, the *CurieuzeNeuzen* project originated within the Ringland initiative, and could build at regular intervals on its **mobilisation power,** its **strategic reflection capacity** and communication services, and its logistical support.
Secondly, the reputation and credibility of Ringland further facilitated access to academic networks and the city of Antwerp. After a laborious project negotiation around the proposal, the research design was settled. The necessary funding from the partner-sponsors followed, though a substantial share came from crowd funding. More importantly, **policy relevance and adoption** was strengthened as the negotiations and engagements resulted in a closer collaboration of the research project team with these partners. For example, the city administration is considering to use the results of *CurieuzeNeuzen* as baseline to monitor the effects of the LEZ as of 2017 in Antwerp. Meanwhile, the government's desire to be more inclusive and actually engage citizens is also met.
Thirdly, while there was support from Ringland at different stages, the *CurieuzeNeuzen* project was careful to keep **a certain distance from Ringland**. The scientific independence of the research was prioritized to guarantee that the advocacy agenda of Ringland would not be conflated with the research agenda. All the communication with participants was done under the *CurieuzeNeuzen* banner, avoiding direct mailing from Ringland unless participants had indicated interest in receiving information about Ringland. The same applied to communication with the press and the city administration. This allowed the team to keep its scientific credibility, and avoided a situation where participants felt that they were pushed into endorsing Ringland if they wanted to participate in *CurieuzeNeuzen*.

Fourthly, through the **diversity in the technical skills of the project team**, the project had direct access to professional communication, high level programming, database management, statistical analysis, survey management, etc.

5.2 Successful Co-created Citizen Science Initiative

The *CurieuzeNeuzen* project can be regarded as a co-creative citizen science programme (Bonney, Ballard, et al. 2009; Bonney, Cooper, et al. 2009) since the project originated from the bottom-up, was implemented through the joint efforts of volunteer-experts, and a team of engaged citizens (see also Section 3.2). During the design and start-up phase contacts with three research institutes were gradually established and later on formalised. This collaborative nature is also mirrored in the funding of the project, which combines crowd funding with contributions by three research institutes, the city of Antwerp and Ringland. Furthermore, *CurieuzeNeuzen* can be considered a successful co-creative or bottom-up citizen science initiative for additional reasons. Firstly, the project started from the bottom-up, but unlike other bottom-up citizen science initiatives did not lack organisational capacity or research validity (Bradshaw 2003); the project has reached not only scientific objectives but also political ones. Secondly, the project reached a diverse audience directly (actual participants) and indirectly. Participants engaged in the project team were involved in all steps of the research process, from the set-up, to the data analysis and the eventual evaluation. Additionally, all participants were encouraged to attend several public feedback moments organised together with opinion makers, multiple knowledge institutions, and politicians, that were always framed within the bigger mobility context. The *CurieuzeNeuzen* air quality results have further fed the political discussion about the necessary mobility measures to take (cf. public transport, LEZ, etc.). Thirdly, in the survey, many participants reported to have learned new things, to have changed, or adjusted their attitude towards mobility measures and their behaviour with respect to displacement patterns. Additionally, an ambitious project as the Ringland initiative is increasingly considered a plausible way of realising a better quality of life in Antwerp. The *CurieuzeNeuzen* project appeared successful in building social capital and bridging the gap between the scientific and the practice as indicated by the broad project outreach.

5.3 Limitations

Despite the many efforts to engage inhabitants in the project from all ranges of society, a bias towards higher educated people, aged between 26 to 50 years, was visible. The project's strategies to engage with the large group of citizens with a migration background were only partially successful. Secondly, the analysis of the participants' profile, motivations, and perceptions was constrained by the limited number of questions in the survey. The project team did not want to put off participants with a long list of survey questions. Additional in-depth interviews with a selection of participants would have increased the insights in how they experienced the project and get a better understanding if the expressed intentions about sustainable mobility were likely to be acted upon. Thirdly, as the project was careful to preserve a certain distance from the advocacy role of Ringland, this did affect the survey. Questions about Ringland were avoided as much as possible to avoid scaring away the large group of participants that were interested in the study, but were not necessarily supportive of Ringland. Fourthly, as the main focus was on gathering air quality data, the social and learning aspects were at first not elaborated and gained attention during the campaign. Therefore, by the end of

the project, the surveys were prepared and distributed rapidly (by volunteers from the project team) and by lack of enough ICT-experience and time, accurately matching answers from the first and second survey appeared infeasible in the end. Nevertheless, we do not think this makes the results and interpretation less relevant, but the interpretation is much more indicative and therefore we consider it a missed opportunity to make our contribution even more valuable.

6 Conclusions

The *CurieuzeNeuzen* project can be considered successful in the way it created both internal (contributions to personal learning and development) and external value (public utility of data for decision-making process) (Conrad and Hilchey 2011). In the aftermath of the project, Ringland and other civil pressure groups were given an active role in the further mobility decision-making process.

The project allowed the measuring of air quality on a very detailed and large scale, and the involvement of volunteers from all over Antwerp. The project showed a highly variable air quality from street to street with the proximity to major roads (i.e. the ring road and Singel) amongst the most contributory factors to local air quality. Nearly half of the measurement locations registered NO_2 concentrations that are expected to exceed the WHO yearly limit. Hence, the sensitizing effect of both participation in the project and the project results themselves that were dramatically displayed as red dots on the map, were substantial. The project roused a sense of urgency to act among inhabitants and politicians to act. After the project, participants indicated in a survey to have improved their scientific insights and knowledge on air quality. Moreover, they reported to have adjusted their attitude towards mobility measures and certain behavioural change was explicated (cf. use of the bike, preference for car-free routes, car sharing, informing other people, etc.). The survey results illustrate that the *CurieuzeNeuzen* project builds toward knowledge accumulation, through which social capital and eventually behaviour change can be catalysed. Future research could focus on the longer-term effects of this kind of project on participants. Further improving the participation rates of citizens with a migration background and other hard-to-reach groups is also a future challenge.

Notes

[i] Legal population in Antwerp as of January 1, 2016 (http://statbel.fgov.be/).

[ii] The type of Palmes diffusion tubes that were used in the *CurieuzeNeuzen* project, were tested by the Flanders Environment Agency in earlier research and gave reliable results

[iii] From these another 2% of the sets were disqualified by the laboratory doing the quality control and analysis.

[iv] However, the *CurieuzeNeuzen* project specifically addressed road traffic and therefore used the NO2 pollutant as indicator. For measuring direct aircraft-related emissions and impacts on ambient air pollution in the surroundings, other pollutants are more appropriate and indirect airport activity related pollution should also be taken into account (Masiol and Harrison 2014)

[v] This total number is re-constructed from the answers provided by a representative sample of *CurieuzeNeuzen* participants to a range of questions about the number of people (separate questions for family, friends, neighbours, etc.) they had talked to about *CurieuzeNeuzen*.

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Annex I: Profile of participants

Table 1. *Age (n: 1395)*

Age	% of participants
16-20	0.2
21-25	1.8
26-30	12.5
31-35	16.3
36-40	15.2
41-45	14.6
46-50	9.1
51-55	8.5
56-60	8.1
61-65	8.1
66-70	3.7
more than 70	1.9

* Data for the City of Antwerp was retrieved from https://stadincijfers.antwerpen.be/databank/

Table 2. *Gender (n: 1398)*

Gender	% of participants
Male	46
Female	54

Table 3. *Highest diploma (n: 1410)*

Highest diploma	% of participants
Primary education	0.6
Secondary education	13.3
Higher education	80.6
No diploma or unknown	5.5

Table 4. *Family situation (n: 732)*

Family situation	% of participants
Single (without children)	15.3
Single parent with children	9.2
Living together or married (without children)	22.1
Living together or married (with children)	50.5
Other	2.9

Annex II: Project's Outreach

Table 5. *How many other people did you talk with about the CurieuzeNeuzen research and or de results? (n: 663)*

People talked to	Total
Friends	3489
Family members	2706
Neighbours	4200
colleagues at work	1739
During other social activities (sportclub, school, ..)	1648
Total (for 660 participants)	11982
Total (estimate: 1950 participants)	35400

Figure Captions

Figure 1. *CurieuzeNeuzen* measurement locations and air quality results.
Figure 2. Has your attitude changed regarding possible solutions to improve air quality (compared to before the start of *CurieuzeNeuzen*)? (n: 660)
Figure 3. Are there things you are doing differently or plan to do differently because of your participation to *CurieuzeNeuzen*? (n: 665)